






# PAF Preliminary Analysis

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<http://paf.web.cern.ch/paf/>

-  Physics guidelines
-  Maximizing  $\int L dt$  in LHC
  - reduction of turn-around time
  - improvement of injectors
  - LHC luminosity upgrade
-  Scenarios for the proton accelerator complex
-  Preliminary recommendations
-  Next steps

## 1. LHC

- “Maximize integrated luminosity”
  - ⇒ Minimize turn-around time by improving reliability / minimizing duration of stops **(L1)**
  - ⇒ Remove bottle-necks towards ultimate luminosity **(L2)**
  - ⇒ Refine / select scenario for SLHC (start in ~ 2015); progressive implementation **(SL)**
- “Be ready to prepare for DLHC” **(DL)**

## 2. Neutrino physics

- Until the physics case is clear (~ 2010)
  - ⇒ Pursue development for { $\beta$ -beam + super-beam} **( $\beta$ B)** and  $\nu$  factory **( $\nu$ F)**
  - ⇒ Depending on physics and outcome of technical developments, elaborate a proposal for a  $\nu$  facility at CERN
- After ~2010
  - ⇒ Implement a  $\nu$  facility at CERN

## 3. Other physics [physics with kaons (**k**), muons ( **$\mu$** ), heavy-ions (fixed-target), antiprotons and nuclear physics (**NP**)]

- Complement the accelerators resulting from the needs of priorities 1 & 2
- Adapt experiments to the capabilities of the accelerators

# Maximizing integrated luminosity (1/3)

- Minimize turn-around time by improving reliability / minimizing duration of physics interruptions (L1)

- Consolidation. Example of acute needs:

- PS magnets:

- 25 dipoles refurbished in 2005 (1st part of “phase 1”)
    - rate for continuation: 8 additional dipoles / year (end of “phase 1” in 2010)

- PS generatrix:

- Obsolete technology (rotating machine)
    - Rotor part having hit the stator (shutdown 2005-2006)

- SPS magnets:

- 7 leaks detected in 2004...
    - Repair => ~1 day lost for physics/magnet
    - More measurements and proposal for extensive consolidation by the end of 2006



- Minimize aging / decrease LHC filling time

- Reduce irradiation implementing a low loss multi-turn extraction in the PS for CNGS
  - 0.9 s cycling rate of the PSB and shorter acceleration cycle in the SPS

# Maximizing integrated luminosity (2/3)

## – Improvement of the injectors (L2)

### ■ Improvement of the SPS

- Reduce impedance to increase thresholds for instabilities
- Increase peak RF capability

### ■ Increase injection energy in the PSB (→ **Linac4**)

- Incoherent space charge tune spread at 50 MeV limits PSB performance. Even with 2 PSB batches, the ultimate beam for LHC cannot be obtained at the PS exit.
- With Linac4 injecting at 160 MeV, a factor of 2 is gained

$$\Delta Q_{sc} \propto \frac{N_b}{\epsilon_{x,y}} \cdot \frac{1}{B_b \beta \gamma^2}$$

with  $N_b$  : number of protons/bunch

$\epsilon_{x,y}$  : normalized transverse emittances

$B_b$  : bunching factor (average/peak line density)

$\beta\gamma$  : classical relativistic parameters

⇒ **Single batch injection in the PS + reduction of the LHC filling time**

### ■ Increase injection energy in the SPS (→ **PS+ / PS2**)

- Reduced space charge tune spread
- Smaller beam size => reduced loss at high intensity
- Higher threshold for Transverse Mode Coupling Instability and coupled bunch transverse instabilities in H-plane due to e-cloud
- Shorter acceleration time (- 10 %)

# Maximizing integrated luminosity (3/3)

- Refine / select / progressively implement scenario for SLHC (SL).

## ■ Phase 0: without hardware changes in the LHC

- Improve injectors ( $\Rightarrow$  actions L1 and L2) to increase brightness  $N_b/\varepsilon$  up to ultimate
- collide beams only in IP1 and IP5 with alternating H-V crossing:  
 $\rightarrow L_0 = 2.3 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$  &  $\int L dt \sim 1.5 \times \text{nominal}$  ( $= 100 \text{ fb}^{-1} / \text{year}$ )
- increase the dipole field from 8.33 to 9 T:  $\uparrow E_{\text{max}} = 7.54 \text{ TeV}$

## ■ Phase 1: with major hardware changes in the LHC (IR, RF, collimation, dump, ...)

- modify the insertion quadrupoles and/or layout:  $\downarrow \beta^* = 0.25 \text{ m}$
- increase crossing angle  $\theta_c$  by  $\sqrt{2}$ :  $\uparrow \theta_c = 445 \mu\text{rad}$
- halve bunch length with new high harmonic RF system in the LHC:  
 $\rightarrow L_0 = 4.6 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$  &  $\int L dt \sim 3 \times \text{nominal}$  ( $= 200 \text{ fb}^{-1} / \text{year}$ )
- double the number of bunches [ $\Rightarrow$  new RF systems in the injectors (including SPS if 12.5 ns bunch spacing)] & increase  $\theta_c$ :  
 $\rightarrow L_0 = 9.2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$  &  $\int L dt \sim 6 \times \text{nominal}$  ( $= 400 \text{ fb}^{-1} / \text{year}$ )

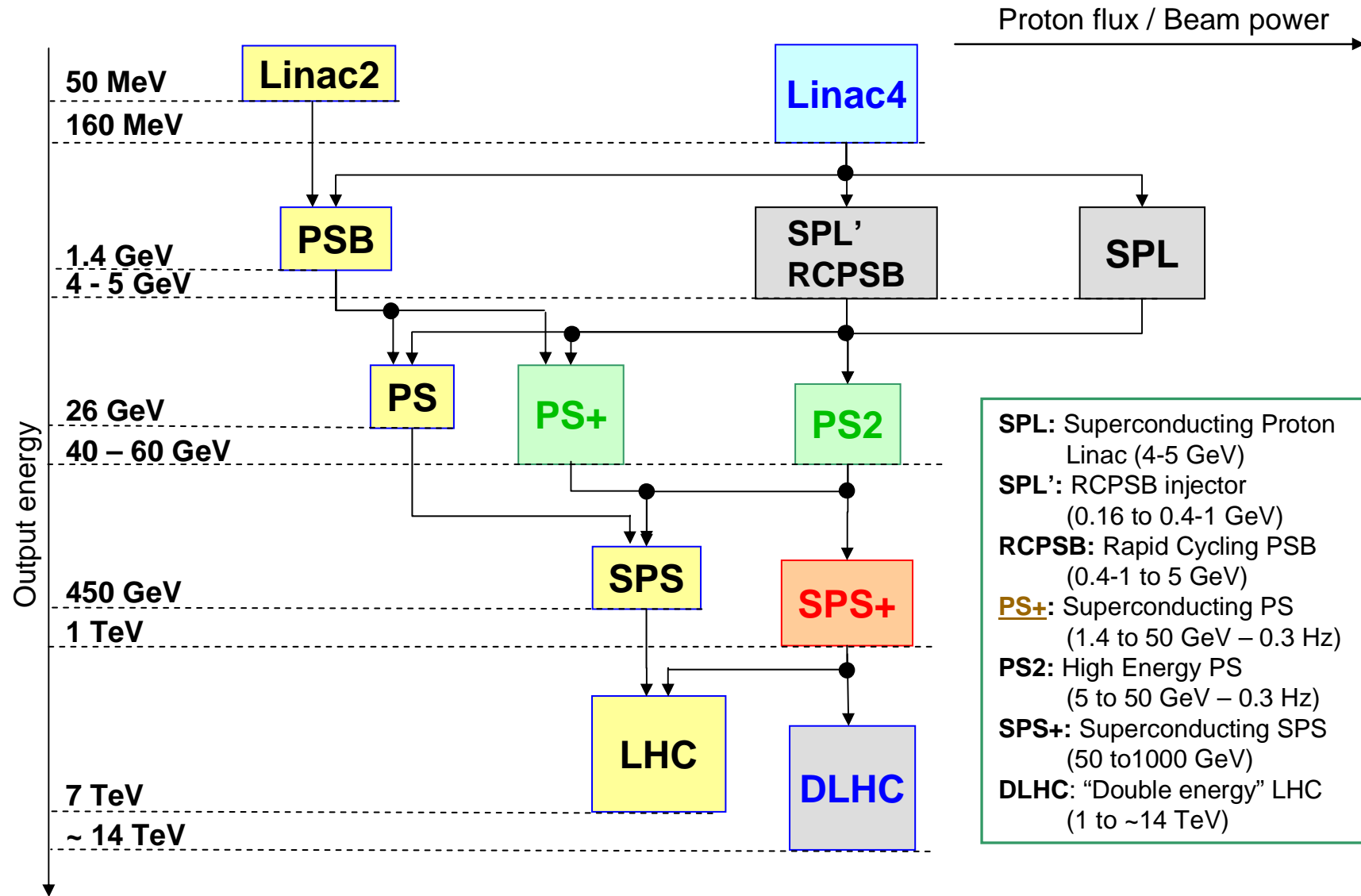
## ■ Phase 2: with a new 1 TeV injector (SPS+)

- $\rightarrow$  doubling of intensity per bunch at constant brightness
- $\rightarrow$  ultimate reduction of turnaround time (factor up to 2) by simplification of LHC injection setting-up  
 $\rightarrow$  factor of up to 1.4 in  $\int L dt$   
 $\rightarrow L_0 = 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$  &  $\int L dt \sim 10 \times \text{nominal}$  ( $= 600 \text{ fb}^{-1} / \text{year}$ )
- $\rightarrow$  preparatory step towards DLHC

# Scenarios for the proton accelerator complex (1/2):



## - Proposed combinations



## Scenarios for the proton accelerator complex (2/2):

- Stages of implementation

	1	2	3	4
	<i>Linac4</i> PSB PS SPS	<i>Linac4</i> PSB <i>PS+ or (PS &amp; PS2)</i> SPS	<i>Linac4</i> <i>SPL</i> <i>PS+ or PS2</i> SPS	<i>Linac4</i> <i>SPL</i> <i>PS+ or PS2</i> <i>SPS+</i>
<b>L1, L2</b>	Ultimate beam from PS	Ultimate beam from SPS	PSB & PS replaced Ultimate beam from SPS	PSB, PS & SPS replaced
<b>SLHC</b>	+	++	++	+++
<b>DLHC</b>	+	++	++	+++
<b><math>\beta</math> beam</b>	-	-	++ ( $\gamma \sim 100$ )	++ ( $\gamma \sim 200$ )
<b><math>\nu</math> Factory</b>	-	-	+++ (~5 GeV prod. beam)	+++ (~5 GeV prod. beam)
<b>k, <math>\mu</math></b>	-	~200 kW beam at 50 GeV	~200 kW beam at 50 GeV	~200 kW beam at 50 GeV
<b>Nuclear Physics</b>	-	-	+++	+++

# Preliminary recommendations (1/3)

## ■ Extensive consolidation

- of the injectors:
  - PS magnets (phase 1) + SPS magnets (procedure to be defined by end 2006)
  - other items (to be analysed later)
- of the LHC
  - implement all “delayed” equipments
  - bring-up to the nominal (if possible ultimate) performance level

## ■ Intensive machine studies (all machines)

## ■ Short & Medium term improvements of the injectors:

- Reduction of SPS impedance (kickers + ?)
- Reduction of the SPS & LHC filling time (900 ms cycling period for the PSB, reduced acceleration time in the SPS...)
- Reduction of the irradiation of the PS (new multi-turn ejection)

## ■ Construction of Linac4

- Design report in autumn 2006



## Preliminary recommendations (2/3)

**Prepare for submission of project proposals in ~ 2010 and for subsequent construction of:**

- ❑ upgrades for SLHC
- ❑ new injectors
- ❑  $\nu$  facility

**⇒ Vigorous efforts on:**

- ❑ accelerator design [SLHC, proton RCS,  $\nu$  factory (ISS),  $\beta$ -beam, ...]
- ❑ design of accelerator components (high power RF, normal conducting magnets, ...)
- ❑ radio-protection / environmental impact studies

**⇒ Aggressive R & D on:**

- ❑ high field magnets (LHC IR, DLHC dipoles ?)
- ❑ fast cycling superconducting magnets
- ❑ superconducting RF
- ❑ high power targets

## Preliminary recommendations (3/3)

**Additional internal resources (manpower and material) inside CERN are mandatory for any of the goals envisaged!**

### **It is worth commenting that:**

- The EU-supported programmes (mostly CARE and EURISOL) are already contributing. Extending and strengthening them would be very beneficial.
- The LARP programme in the USA will provide important contributions. Its extension and strengthening would be highly welcome.

### **But more is clearly needed, both in terms of organization and resources.**

#### **Suggestions:**

- Setting-up of an internal team in charge of preparing a design report for the LHC upgrade
- Active CERN participation in the BENE-supported study for a  $\nu$  facility (ISS).  
+ Decision as soon as possible for the type of  $\nu$  facility to be built and setting-up of an internal team in charge of preparing a design report
- Request for additional EU-supported programmes in collaboration with other European laboratories / universities (e.g.: Design Study for a Neutrino Factory).
- Additional contributions...

**The ambitions of the future CERN proton and  $\nu$  programmes will be determined by the level of support from inside and outside the organization.**

## Next steps

### R. Aymar's requests:

- Budget profiles of the recommended actions
- Priorities

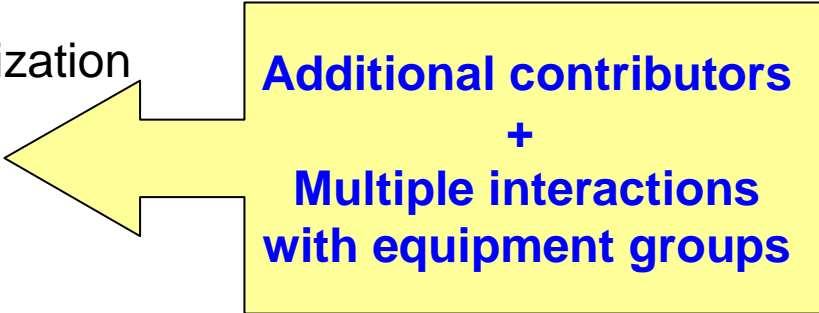
### Schedule (defined by the agenda of the CERN Council Strategy Group):

[\[http://council-strategygroup.web.cern.ch/council-strategygroup/\]](http://council-strategygroup.web.cern.ch/council-strategygroup/)

- Plans for the LHC upgrade → Open Symposium (Orsay 30/01 – 1/02)
- Overall strategy → CCSG workshop (Zeuthen 2/05 – 6/05)
- Detailed data → CERN council (Lisbon July)  
→ Medium Term Plan (Autumn)

### PAF plans:

- 6/02: distribution of tasks & work organization
- Week 11: first data set with priorities
- Week 16: draft report
- Week 21: final report



**Additional contributors  
+  
Multiple interactions  
with equipment groups**

# ANNEX

# R & D on fast cycling superconducting magnets



## ■ 2 types of dipoles

	Peak field	Ramp-rate	Cycle	Aperture	Length	Salient aspects
PS+	3.5 T	4 T/s	3.6 s	$\Phi$ 150 mm	4 m	High ramp-rate, large aperture
SPS+	4.5 T	1.5 T/s	12 s	$\Phi$ 80 mm	6 m	Moderate ramp-rate, higher field

## ■ 2 types of superconducting wires / cables

	Filament $\Phi$	Matrix	Cable $R_a$	Cable $R_c$	Status of wire
PS+	$\sim 1 \mu\text{m}$	Cu-Mn or Cu-Ni	$>0.8 \text{ m}\Omega$	$>40 \text{ m}\Omega$	Feasible, but need R&D and industrialization
SPS+	$< 3 \mu\text{m}$	Cu-Mn or Cu-Ni	$>0.3 \text{ m}\Omega$	$>10 \text{ m}\Omega$	



- industrialize  $3 \mu\text{m}$  filaments in resistive matrix : moderate R&D, billets, measurements
- develop  $1 \mu\text{m}$  filaments in resistive matrix : massive R&D, billets, filaments
- optimize wire coating techniques to achieve the required electrical and thermal properties
- study stability of cables as a function of adjacent and cross inter-strand resistance
- establish, and validate with experimental results, loss computations models
- build instrumented model magnets to provide feedback to wires/cables

# Importance of reducing the “turn around time”



- Machine parameters and initial luminosity  $L_0$ , determine the luminosity life-time  $\tau_L$
- For a given  $T_{\text{turnaround}}/\tau_L$  there is an optimum  $T_{\text{run}}$  maximizing  $\int L dt$
- It is always worthwhile to reduce  $T_{\text{turnaround}}$ , and even more so when  $L_0$  is increased because  $\tau_L$  is decreased

$$T_{\text{run}} \text{ (optimum)} \Rightarrow \begin{cases} 1 + \frac{T_{\text{run}} + T_{\text{turnaround}}}{\tau_L} = e^{\frac{T_{\text{run}}}{\tau_L}} \\ \text{Average}(L) = L_0 \times \frac{\tau_L}{T_{\text{run}} + T_{\text{turnaround}} + \tau_L} \end{cases}$$

**Examples with  $\tau_{\text{gas}} = 85$  h and  $\tau_{\text{IBS}}^* = 106$  h (nom)  $\Rightarrow$  40 h (high-L)**

$L_0$ [cm <sup>-2</sup> s <sup>-1</sup> ]	$\tau_L$ [h]	$T_{\text{turnaround}}$ [h]	$T_{\text{run}}$ [h]	$\int_{200 \text{ days}} L dt$ [fb <sup>-1</sup> ] <b>gain</b>	
$10^{34}$	15	10	14.6	66	x1.0
$10^{34}$	15	5	10.8	85	x1.3
$10^{35}$	6.1	10	8.5	434	x6.6
$10^{35}$	6.1	5	6.5	608	x9.2

